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Dual Task During Encoding, Maintenance, and Retrieval in Alzheimer's Disease

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Abstract. Previous dual task studies have demonstrated minimal costs when healthy individuals simultaneously perform two tasks at their own individual ability levels. Conversely, Alzheimer's disease (AD) patients show dual task decrements, but it is unclear whether the problem arises at the encoding, maintenance, and/or retrieval phases of memory. Two experiments combined digit recall and visuo-motor tracking to investigate dual task effects during encoding, maintenance, and/or retrieval for AD patients compared with healthy adults. The demands of each single task were titrated for the ability of each participant. In Experiment 1, the dual task requirement was present throughout both encoding and retrieval of digit recall and the differential dual task effects on a secondary tracking task were examined *post-hoc*. In Experiment 2, the impact of dual task during encoding only, during maintenance only, and during retrieval only was examined systematically. The findings suggest that the specific AD deficit reflects impairment of a cognitive function that supports the simultaneous performance of two tasks in the healthy brain, particularly during the encoding and retrieval phases of the memory task.

Keywords: Alzheimer's disease, dual task, encoding, maintenance, retrieval, working memory

INTRODUCTION

Alzheimer's disease (AD) is thought to be a disease of neuroplasticity where certain neurobiological systems are attacked by amyloid (resulting in senile plaques) and tau hyperphosphorylation (resulting in neurofibrillary tangles) [1–4]. As Alzheimer pathology is concentrated most in the structures of the temporal lobe, particularly the amygdala, the hippocampus, and the entorhinal cortex [5], damage to the systems responsible for learning is typically the earliest feature of AD. Patients with early AD perform poorly on

tasks such as free recall, delayed recall, and recognition memory [6–8] (for review, see [9,10]).

While episodic memory impairment is clearly the most salient aspect of AD, such impairments are also reported in healthy older adults, making it difficult to use retentive impairments alone to assist in diagnosis of AD [11–13]. Moreover, studies have shown that measures of memory impairment rapidly reach floor levels as the disease progresses, making it difficult to monitor disease progression [14–16]. Deficits in executive abilities and attention may also develop during the course of AD [17]. Patients with AD may demonstrate impairment in the ability to perform two tasks concurrently, despite being able to perform the tasks separately relatively well [18–22]. In contrast, healthy younger and older individuals are able to perform these kinds of tasks simultaneously with relatively little decrement in performance on either task compared to single task

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performance [20–26]. This AD-specific dual task decline is independent from overall cognitive demands, as reducing the demands of the two single tasks does not remove the dual task effect [20]. Furthermore, the dual task impairment reported in AD patients increases with disease progression [18].

The relative lack of dual task interference in healthy adults has been related to the operation of a multiple component working memory system with each task performed by separate, domain specific cognitive resources that can operate in parallel [27–29]. One set of resources has been identified as a phonological store coupled with a phonological rehearsal system, which together play an important role in the temporary retention of verbal information [30,31]. A second set of resources comprises a visual cache providing temporary memory for visual appearance and location and an ‘inner scribe’ thought to maintain dynamic spatial information such as movements or pathways [29,32,33]. For example, orally recalling a sequence of recently presented digits while tracking a moving target around a screen [19,20], or holding a digit sequence in memory while, at the same time, remembering and recalling an abstract visual pattern [24]. According to this view, there will be little disruption when two tasks are performed simultaneously, providing they do not employ the same cognitive mechanisms. A number of dual task studies have demonstrated that, in healthy adults, it is the nature of the tasks performed simultaneously that influences whether or not there are significant dual task decrements and not the overall demands of performing the tasks at the same time [24,34–36]. Moreover, brain imaging studies with healthy participants have provided evidence suggesting that dual task co-ordination recruits different anatomical networks from those used for performance of each single task [37–39] (for critical reviews see [40,41]). In healthy individuals, therefore, there may be an additional ‘executive’ resource that is engaged when performance of two concurrent tasks is required (see also [42]). A deficit in dual task coordination is said to reflect a selective failure in this central executive mechanism [18–20,43,44].

However, which specific phase of the memory process – encoding, maintenance or retrieval – is most susceptible to dual task impairments in AD remains a matter of speculation. For example, Germano and Kinsella [45] and White and Ruske [46] suggested that AD patients might have a particular problem at encoding. The main aim of this study is to address whether dual task requirements impose their greatest demand during encoding, maintenance, or retrieval in AD patients.

Our own previous experiments with AD patients have tended to use a combination of perceptuo-motor tracking and immediate serial ordered recall of digits to examine overall dual task performance [18–20]. Experiment 1 therefore addressed the issue of dual task performance when digit recall and tracking were combined, analyzing separately the tracking performance during encoding and during retrieval in AD patients and healthy older people.

EXPERIMENT 1

METHODS

Participants

Eight AD patients (4 men, 4 women) recruited through the Outpatient Memory Disorders Clinic, Cornhill Hospital, Aberdeen, UK, were included in Experiment 1. The diagnostic criteria of the National Institute of Neurological and Communicative Disorders and Stroke and the Alzheimer’s Disease and Related Disorders Association for probable Alzheimer’s disease [47] were followed, including medical, neurological, and neuropsychological screening to rule out any other possible dementias. All patients showed obvious evidence of deterioration over a period of no less than 6 months and no one had a history of other neurological or psychiatric diseases or alcohol or drug abuse. The AD patients had a mean age of 74.1 years ($SD = 2.4$, range = 70–77), a mean education of 10.0 years ($SD = 1.4$, range = 9–12), and a mean Mini Mental State Examination (MMSE) [48] score of 21.1 out of a possible 30 ($SD = 2.3$, range = 18–24).

Eight healthy participants (4 men, 4 women) aged between 64 and 80 years ($M = 72.3$, $SD = 6.4$) with a mean education of 10.6 years ($SD = 1.8$, range = 9–14) recruited from the panel of volunteer participants at the University of Aberdeen were also tested as controls. As members of the panel, volunteers are routinely cognitively assessed and anyone whose performance suggests that there may be an underlying cognitive impairment is removed from the panel. The control group did not significantly differ in age or education from the AD group ($p = 0.45$ and $p = 0.46$, respectively). Informed consent was obtained for all research volunteers according to the Declaration of Helsinki and the study was approved by the Grampian (UK) Research Ethics Committee.

Background neuropsychological measures

The AD group were administered the Token Test [49] as a test of language comprehension and the PFL version of verbal fluency [50] to assess executive dysfunction. Memory performance was assessed using rehearsal learning [51]. Patients' relatives were asked to fill in the Dysexecutive Questionnaire (DEX) [52], which forms part of the Behavioural Assessment of the Dysexecutive Syndrome [53] to assess severity of any dysexecutive symptoms.

Experimental tasks

Digit recall. The initial phase for digit recall involved assessment of individual span. Participants were played lists of digits, recorded by a female native English speaker, at a rate of two digits per second. Immediately after presentation, participants were asked to recall the digits orally in the serial order of presentation. Participants were first presented with a sequence of two digits, and the sequence length was increased by one digit following successful immediate serial ordered recall of two out of three sequences. The process of incrementing sequence length continued until the participant failed to recall at least two out of three sequences at a given sequence length. Digit span for each individual was taken to be the maximum sequence length at which they could remember two out of three sequences correctly. There were no time restrictions for recall.

Tracking. Participants were asked to keep a light-sensitive stylus (light pen) on top of a red oval with dark spots (resembling a 'ladybird' or 'ladybug' approximately 2.5 cm long and 2 cm wide) while it randomly moved around a computer screen. The ladybird remained red as long as the light pen was in contact with it, but it changed to green immediately when contact was lost, returning to red when contact was regained. The computer screen was placed within a specially constructed table at an angle of 30 degrees from the horizontal, with the horizontal midpoint of the screen approximately at elbow level for a seated participant. This arrangement was found to be less physically tiring than attempting to track on a vertical screen [18–20]. The speed of the ladybird could be set at different levels. The slowest speed corresponded to movement of the target at approximately 3.5 cm per second. The minimum difference between each level of speed was about 1 cm per second. For example, the speed at level

2 was approximately 4.5 cm per second, whereas the speed at level 10 was about 12.5 cm per second.

In the initial phase assessing tracking ability, the ladybird moved slowly around the computer screen at approximately 4.5 cm per second. If the participant maintained contact with the target for at least 60% of the time over a period of five seconds, the speed was increased by 1 cm per second. However, if during the previous five seconds the participant was in contact with the stimulus for less than 40% of the time, the speed decreased by 1 cm per second. This process of increasing and decreasing target speed continued until the percentage time on target was between 40% and 60% for 15 seconds (three five second periods) and this speed was taken as the participant's individual tracking ability. To avoid fatigue from continuous arm movement over an extended period, the change in speed for the low levels (speed levels 1 to 5) involved a shift of one level at a time, whereas higher speed levels (> 5) involved a shift of two levels.

General procedure

After the individual ability levels for each participant performing digit recall and tracking were assessed using the procedure described above, participants were asked to perform the two tasks individually and then concurrently. The presentation order for the single digit and tracking tasks was counterbalanced across participants. Both AD patients and controls performed all the individual ability levels, single task and dual task conditions. The first digit sequence and the corresponding time for tracking were considered to be practice and were not included in the final analysis.

Single task. For digit recall, participants were tested for a 90-second period during which they heard a series of lists of digits for immediate serial ordered oral recall. The sequence length for each list was fixed for each individual according to their digit span as measured in the initial phase. A period of one second for each number presented was allowed for recall. The number of sequences presented within each 90-second period was determined by the length of the sequence for each individual. However, the total number of digits across all lists presented was very similar for all participants. The dependent variable was the percentage of correctly recalled digits in the correct position. The first sequence was considered as a run-in and was not included in the final analysis.

For the tracking task, participants were tested for a 90-second period during which they have to main-

Table 1
Mean individual ability levels and single task and dual task performance with standard deviations in parentheses for AD patients and control participants in Experiment 1

	AD patients	Healthy controls
<i>Individual ability</i>		
Digit span	6.25 (1.16)	6.62 (0.74)
Tracking ability (cm/sec)	12.50 (3.70)	14.00 (3.16)
<i>Single task</i>		
Digit recall	81.39 (8.61)	88.11 (6.22)
Tracking	53.39 (8.70)	56.65 (8.00)
<i>Dual task</i>		
Digit recall	80.05 (13.13)	86.13 (7.75)
Tracking	35.33 (11.85)	49.33 (9.85)

tain contact with the target. The speed of the ladybird was based on the individual ability level previously assessed, and speed remained constant at this level for this part of the procedure. The dependent variable was the percentage of time that the light pen remained in contact with the target. The first 10 seconds were considered as a run-in and were not included in the final analysis.

Dual task. Participants were then tested for a 90-second period, during which they had to perform the digit recall and the tracking tasks at the same time. Tracking and digit recall were performed at individual levels assessed as described above, and in each case the dependent variable was accuracy.

RESULTS

Background neuropsychological measures

The AD patients had a mean score of 29.56 out of a possible 36 for the Token Test ($SD = 4.08$, range = 22–35) with patients 1 and 7 performing below the cut-off of 26.5 [49]. A mean of 21.13 words were generated for verbal fluency ($SD = 11.76$, range = 8–39) with patients 2, 4, 6, and 7 performing below the cut-off of 18 [50]. The mean score on rehearsal learning was 17.75 out of a possible 24 ($SD = 6.18$, range = 6–24) with patients 1, 2, 6, and 7 performing below the cut-off of 18.25 [51]. The mean score on the DEX was 36.25 out of a maximum of 80 ($SD = 16.71$, range = 20–65) where the higher the score, the greater the severity of executive dysfunction. Only patient 4 performed above the 95th percentile of 61 [52].

Individual ability

Table 1 reports the individual digit span and tracking speed means and standard deviations for each group. Separate independent samples t-tests revealed that the two groups did not significantly differ in terms of their digit span levels ($p = 0.46$) or tracking ability levels ($p = 0.40$). Furthermore, the two groups did not significantly differ in terms of their single task digit recall ($p = 0.10$) or single task tracking performance ($p = 0.45$). This means that the AD patients and healthy controls' individual ability levels did not significantly differ in order to obtain a similar percentage accuracy during the single task conditions.

Dual task performance

Digit recall. Table 1 also shows the dual task digit performance of each group. The data from the single and dual tasks were entered into a 2 (group: patients versus controls) \times 2 (condition: single/dual) mixed design ANOVA with group as the between-group variable and condition as the repeated measures variable. No significant main effect of group ($p = 0.16$) or condition ($p = 0.36$) or a two-way group \times condition interaction ($p = 0.86$) were found.

Tracking. The tracking task performance for both groups is in Table 1. Again a 2 (group) \times 2 (condition: single/dual) mixed design ANOVA showed a significant effect of condition [$F(1, 14) = 34.80$, $p < 0.0001$, $\eta_p^2 = 0.71$] and a significant interaction [$F(1, 14) = 6.24$, $p < 0.05$, $\eta_p^2 = 0.31$]. Bonferroni post hoc t-tests showed a significant difference between the patients' performance on the single and dual tasks ($p < 0.002$);

Table 2

Percent change = $\frac{\text{Single task performance} - \text{dual task performance}}{\text{Single task performance}} \times 100$
Then the percentage change for each test was combined as follows:
Combined percent change = $100 - \frac{(\text{Percent change digit task} + \text{Percent change tracking task})}{2}$

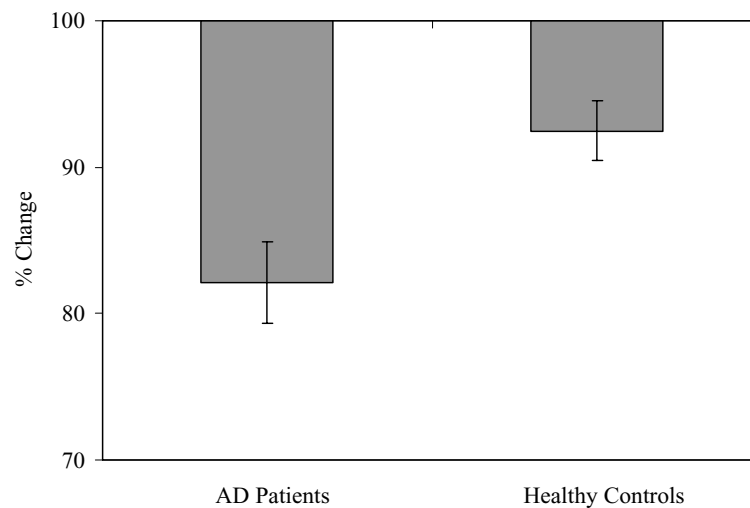


Fig. 1. Overall mean percentage change (with standard error bars) between single and dual task performance in digit recall and tracking combined.

no significant difference was found in performance between the single and dual task conditions for the control group. The main effect of group was not significant ($p = 0.06$).

Overall dual task change

For each participant, the percentage change in accuracy that occurred between the single and dual tasks for the digit and tracking tasks was calculated according to the following formula in Table 2.

According to this formula, one can calculate the overall change between single and dual task performance. A score of 100 means that no change occurred, single and dual task performance was equal; a score over 100 means that an improvement during dual task occurred and a score below 100 means that a decrement in dual task occurred. Figure 1 shows the overall change for both groups. Although Levene's test for equality of variance demonstrated that the assumption of homogeneity of variance was met, the scores for each group were not normally distributed. Therefore, a Mann Whitney U-test was conducted which showed a significant effect of group ($U = 7.0$, $z = -2.63$, $p < 0.01$) where the AD patients showed a significantly greater overall dual task decrement than the healthy

controls. All AD patients showed dual task decrements and yet many of them did not perform below normal limits on some or all of the neuropsychological tests.

Post hoc encoding versus retrieval comparisons

We next considered tracking accuracy separately while digits were being presented for encoding, and when digits were being recalled. There was also a 'gap' period when the participant had completed digit recall on one trial and was tracking while waiting for the next sequence to be presented. Although these occurred during the dual task procedure, there was no dual task requirement as such, and the number of gap periods varied across participants depending on their digit span. Therefore the data for these periods were difficult to categorize and were excluded from this additional analysis. Figure 2 shows the performance of both groups on tracking as a single task, and when combined with digit presentation (encoding), and with digit recall (retrieval). The data from the single task and the encoding and retrieval phases were entered into a 2 (group: AD versus controls) \times 3 (condition: single task, dual task at encoding and dual task at retrieval) mixed design ANOVA with group as the between-group variable and condition as the repeated measures variable.

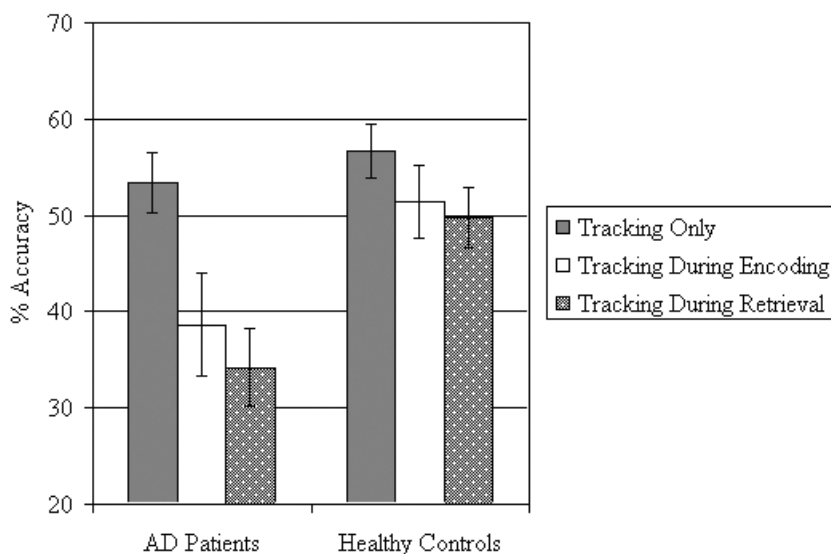


Fig. 2. Mean percentage tracking performance (with standard error bars) in single task, during digit encoding and during digit retrieval for AD patients and healthy participants.

The significant effect of group [$F(1, 14) = 5.37, p < 0.05, \eta_p^2 = 0.28$] showed that AD patients performed significantly more poorly than the healthy older adults. There was a significant main effect of condition [$F(2, 28) = 15.15, p < 0.00001, \eta_p^2 = 0.52$] where single task performance was significantly better than dual task at encoding ($p < 0.001$) and dual task at retrieval ($p < 0.001$). The two dual task conditions did not significantly differ. There was also a significant two-way interaction [$F(2, 28) = 3.36, p < 0.05, \eta_p^2 = 0.19$]. Post hoc comparisons between means showed a main effect of condition for patients, where single task performance differed significantly from both dual task at encoding ($p < 0.005$) and at retrieval ($p < 0.0001$). The mean for dual task at retrieval appeared to be lower than at encoding (see Fig. 2), but this comparison did not reach significance. The controls did not show a significant dual task decrement under either dual task condition.

These results suggest that both dual task at encoding and at retrieval are disruptive for AD patients but not for healthy controls.

DISCUSSION

Previous studies of dual task performance have demonstrated minimal dual task costs when healthy individuals perform two tasks simultaneously. In contrast, even when both single tasks have been titrated

for individual performance, patients in the early stages of AD showed significant dual task costs [18,19,43]. These findings are thought to reflect the operation of a specific dual task co-ordination mechanism within a multiple component working memory system rather than reflecting general cognitive demand on a damaged system [20]. In the current experiment when comparing overall dual task change scores, the AD patients show a significant dual task decrement compared to healthy controls. This lends support to the notion that there is a specific mechanism responsible for coordinating the simultaneous performance of two tasks and that this co-ordination system is impaired in AD. It was not known whether the detrimental effect of the secondary tracking task would affect the performance equally throughout the encoding and retrieval phases. In the current data there is a suggestion that the decrement was particularly evident during the retrieval phase, although encoding and retrieval did not differ statistically.

However, in Experiment 1 the dual task requirement was present throughout both encoding and retrieval. This allowed us only to look at the potential differential effects at encoding and at retrieval on the tracking performance, as we could not examine any differential impact on digit recall. It is not clear whether the overall dual task effect observed in the combined measure for AD patients is due to the combination of a secondary task with the processes of encoding material into memory or of retrieving that material during recall, or is primarily an effect on memory storage. Therefore, Exper-

iment 2 was designed to systematically study the impact of dual task requirements separately during encoding, during a maintenance interval, and during retrieval.

EXPERIMENT 2

METHODS

Participants

Eleven AD patients (9 men, 2 women) were selected from the Outpatient Memory Disorders Clinic, Cornhill Hospital, Aberdeen. All met the same criteria that were used for Experiment 1 [47], but none had taken part in the earlier experiment. All showed clear evidence of deterioration based on a medical, neurological, and neuropsychological assessment over a period of at least 6 months. None of the patients had a history of other neurological or psychiatric disorders or drug or alcohol abuse. The patients were aged between 66 and 82 years ($M = 75.6$, $SD = 6.3$), with 11.6 years of education ($SD = 3.5$, range = 9–18) and a MMSE score of 24.3 ($SD = 3.3$, range = 19–29). The AD patients in Experiments 1 and 2 did not significantly differ in terms of age or years of education ($p = 0.48$ and $p = 0.20$ respectively). However, the patients in Experiment 1 had a significantly lower MMSE score [$t(17) = -2.40$, $p < 0.05$] than did the patients in Experiment 2.

Twelve healthy individuals (6 men, 6 women) from the panel of volunteer participants at the University of Aberdeen also took part in the experiment. The control group had a mean age of 71.4 years ($SD = 4.8$, range = 64–78) and a mean of 12.2 years of education ($SD = 2.6$, range = 9–18). The control group and the AD group did not significantly differ in terms of age ($p = 0.08$) or years of education ($p = 0.63$). Furthermore, the control group did not significantly differ from their equivalent age group in Experiment 1 in terms of age ($p = 0.74$) or years of education ($p = 0.16$). The Grampian (UK) Research Ethics Committee approved this study and participants gave written informed consent according to the Declaration of Helsinki prior to testing.

Experimental tasks

Digit recall. The same digit recall task described in Experiment 1 was adopted in Experiment 2 except that delayed rather than immediate digit span was assessed. When determining delayed digit span, par-

ticipants were required to mentally rehearse the digit sequence for 5 seconds following presentation before commencing their recall. After hearing a tone, participants were asked to recall out loud the sequence in the same order as they previously heard it. As in Experiment 1, the initial digit sequence length was two digits and participants were presented with three sequences at each sequence length. If two out of the three sequences were correctly recalled, the digit sequence was increased by one digit. When participants were unable to accurately recall two of the three digit sequences, digit span was taken as the maximum sequence length at which participants were able to correctly recall two out of three digit sequences.

Tracking. The tracking task from Experiment 1 was used.

General procedure

Experiment 2 consisted of the same three stages as in Experiment 1: the assessment of individual ability, single task performance and dual task performance. Dual task performance was assessed under three conditions: at encoding, during maintenance, and at retrieval of the digit strings. The procedure for assessing the single digit recall and tracking performance was identical to Experiment 1, with the exception that single task digit recall was performed with delayed recall at the individually assessed ability levels. Under dual task conditions, the digit sequence was presented as a preload with a 5 second delay prior to serial recall. There were three dual task conditions in which tracking was performed only during 1) the encoding phase of digit recall; 2) the maintenance phase of digit recall; or 3) the retrieval phase of digit recall. As in Experiment 1, participants performed all the individual ability levels, single task and dual task conditions. Individual ability was always measured before single task performance, which was always assessed prior to dual task performance. However, the presentation order of each task within each stage of the experiment was randomized across individuals. Participants performed three single task trials for digit recall and for tracking, and six trials for each dual task condition.

RESULTS

Individual ability

Table 3 shows the means and standard deviations for the delayed digit spans and tracking abilities of the

Table 3
Mean individual ability levels and single task and dual task performance with standard deviations in parentheses for AD patients and control participants in Experiment 2

	AD patients	Healthy controls
<i>Individual ability</i>		
Digit span	4.91 (0.70)	6.17 (1.47)
Tracking ability (cm/sec)	7.64 (2.62)	9.33 (1.67)
<i>Single task</i>		
Digit recall	93.99 (7.96)	90.14 (10.17)
Tracking	60.13 (13.48)	63.27 (9.67)
<i>Dual task</i>		
Digit recall	85.55 (10.07)	93.07 (4.23)
Tracking	51.51 (14.33)	58.08 (9.97)

AD patients and healthy older controls. To determine whether the 2 groups significantly differed in terms of their individual ability, separate independent samples t-tests were conducted. In terms of the digit span data, AD patients had significantly lower delayed digit spans than the healthy controls [$t(21) = 2.58, p < 0.05$]. The two groups did not significantly differ in terms of tracking speed ($p = 0.08$). Moreover, the two groups did not significantly differ in terms of their single task digit recall ($p = 0.33$) or single task tracking performance ($p = 0.53$). This means that the two groups' individual tracking speeds did not significantly differ in order to obtain a similar percentage for single tracking accuracy. However, for digit recall, the AD patients had significantly lower delayed digit spans in order to achieve similar single task digit recall accuracy as the controls.

Dual task at encoding, maintenance and retrieval

Digit recall. Figure 3 presents the mean percentage accuracy for digit recall under single task and dual task at encoding, maintenance, and retrieval for AD patients and healthy controls. The Mauchly's sphericity test revealed that the repeated measures effect violated the assumption of sphericity and the Levene's test demonstrated that the homogeneity of variance assumption was also violated. Even when transformations were applied to the data, some levels of the repeated-measures condition variable differed in their variance compared to other levels. Therefore, linear mixed effects (LME) analysis using REML estimation [54] was adopted as it has the advantage over the traditional ANOVA approach to modeling the mean response in which the covariance among repeated measures is brought into

the model. It is then unnecessary to require overly restrictive assumptions on covariance structure such as compound symmetry or sphericity, with the attendant difficulties of p-value correction if those assumptions are violated.

LME models of the effects of group and condition and their interaction were estimated with a variety of random effects, and the fits were compared using likelihood ratio tests. The result of this stepwise model comparison approach was that the best fit was obtained with uncorrelated random intercept and random slope of condition, (comparison between this model and the null (intercept only) model has $\chi^2(16) = 32.86$). This model was used in subsequent analysis. The level-1 residuals were inspected to confirm reasonable normality and homogeneity of variance.

Analysis of variance of the fixed effects showed a significant interaction [$F(3,84) = 2.86, p < 0.05$] but non-significant main effects for group and condition ($p = 0.17$ and $p = 0.70$ respectively). The effect size for the interaction effect in the 2×4 ANOVA is small (0.2). This is based on a likelihood ratio R-squared measure [55]. Comparisons of interest were explored in more detail by testing specific contrasts between the fixed effects post-hoc. Results revealed that single task performance was significantly more accurate than dual task at encoding ($p < 0.05$) and dual task at retrieval ($p < 0.05$) but not dual task at maintenance ($p = 0.32$) in the AD patients. There were not significant differences between the single task performance and the dual task conditions in the control group ($p > 0.72$).

Tracking. The mean percentage accuracy for tracking under single and dual task conditions for the two

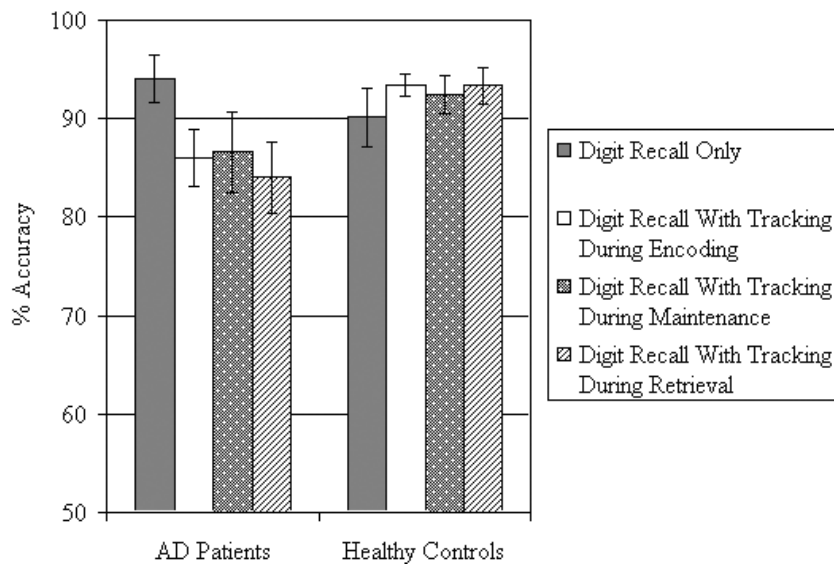


Fig. 3. The mean percentage accuracy (with standard error bars) for digit recall as single task and with dual task at encoding, maintenance and retrieval for AD patients and healthy adults.

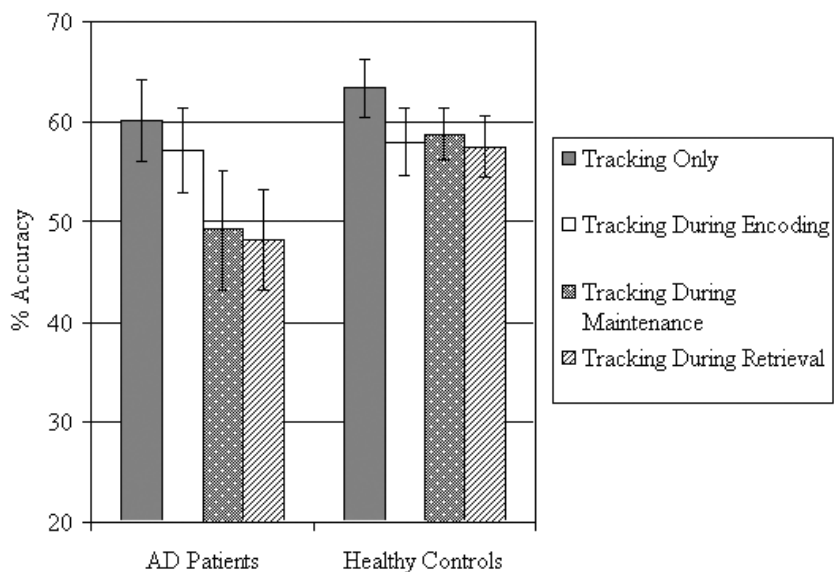


Fig. 4. The mean percentage accuracy (with standard error bars) for tracking under single and dual task conditions for AD patients and healthy adults.

groups is shown in Fig. 4. A 2 (group) \times 4 (condition) ANOVA comparing the AD patients and healthy older controls' tracking accuracy data revealed a significant main effect of condition [$F(3,63) = 5.87, p < 0.005, \eta_p^2 = 0.22$]. There was not a main effect of group or group \times condition interaction. Bonferroni corrected paired samples t-tests showed that participants' tracking accuracy was significantly worse under dual task at maintenance ($p < 0.01$) and dual task at retrieval

($p < 0.01$) conditions but not dual task at encoding compared to single task.

Combined measure. We derived combined dual task scores for each group, separately for the different phases of memory. The means are illustrated in Fig. 5. As the Levene test for homogeneity of variance revealed significant differences in the variance among the groups and transformation of the data did not resolve this, a similar procedure was applied to develop a LME model

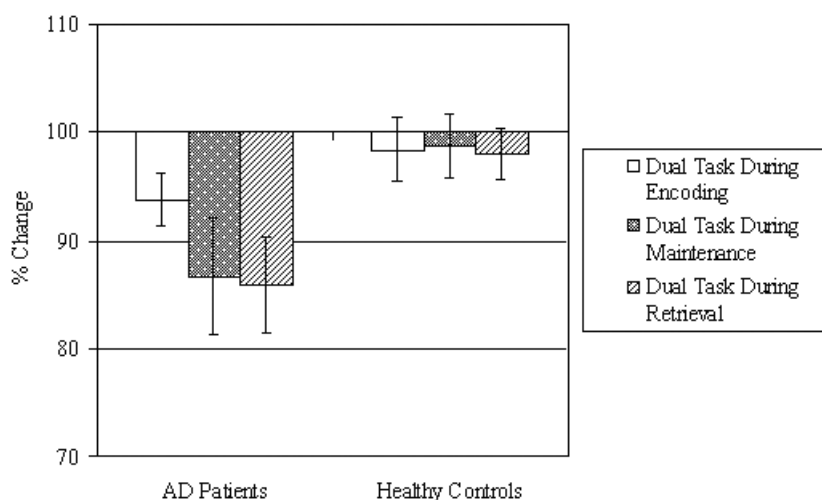


Fig. 5. The combined score (with standard error bars) for dual task at encoding, dual task at maintenance and dual task at retrieval.

of the effects of group and condition. Again, the best model was obtained with the uncorrelated random intercept and random slope of condition (and comparison between this model and the null (intercept only) model has $\chi^2(10) = 20.51$). One patient's performance was removed from this analysis as the patient performed more poorly compared to the other AD patients in the dual task at maintenance condition. Analysis of variance of the fixed effects revealed the group effect was not significant ($p = 0.06$). The condition ($p = 0.22$) and group x condition interaction were not significant either ($p = 0.19$).

DISCUSSION

Experiment 2 was a systematic investigation of the impact of dual task requirements separately during encoding, maintenance, and retrieval. It showed that when healthy participants were asked to perform digit recall accompanied by a tracking task, there was not an effect of dual task on memory at any of the memory phases. In contrast, the AD patients were significantly less accurate at recalling digits when performing a tracking task during encoding or retrieval of the digits. In terms of tracking performance, both groups showed a significant decrement in accuracy during maintenance and retrieval compared to their single task performance.

CONCLUSIONS

We examined the dual task impact separately during encoding, maintenance and retrieval. Across two ex-

periments we have demonstrated that healthy elderly do not show an overt dual task deficit when single task performance is titrated for individual ability. This reinforces previous findings that have also adopted single task titration [18–20,56,57].

On the contrary, the dual task impairment is always very clear in the AD group. AD patients do show a specific difficulty performing two tasks concurrently and may therefore strategically focus on only one task at the expense of the other.

It should be noted that the MMSE scores for the AD patients in Experiments 1 and 2 did significantly differ. However, our previous work suggests that dual task performance is not influenced by MMSE scores, e.g. [21]. Moreover, the dual task paradigms adopted in the two experiments were slightly different. Therefore, it is not possible to directly compare them statistically. In Experiment 1, participants were asked to concurrently perform an immediate digit recall task at span with tracking and post hoc analysis examined the effects of dual task at encoding and dual task at retrieval. While in Experiment 2, participants were asked to perform a delayed digit recall task at span with tracking performed at encoding, maintenance, or retrieval.

The small sample recruited for both experiments do not constitute a problem as our power analyses showed that the size is enough to detect hypothesized differences. Moreover, despite the small numbers in each group and the differences in severity between the AD patients in Experiments 1 and 2, the AD patients were significantly impaired compared to the healthy controls on the combined dual task measure in both experiments.

The dissociation between healthy ageing and AD which has been shown in previous studies [18–22,58] indicates that dual task decrements are specific to the disease. The current experiments suggest that the overall dual-task decrement in AD affects all phases of memory processing, particularly encoding and retrieval (see also [45,46]). However, given the small number of participants included in the study, future work should attempt to replicate these findings in a larger group of AD patients who are at varying stages of the disease process.

It is difficult to use episodic memory impairments alone to assist diagnosis of AD as such retentive impairments also occur in healthy older adults [11–13]. Indeed, it has been shown that the older individuals are, the more likely they are to be misclassified as having AD on the basis of their performance on episodic memory tasks [59]. Moreover, it is difficult to monitor disease progression using episodic measures of memory impairment, as AD patients' performance rapidly reaches floor levels as the disease progresses [14–16]. In contrast, the dual task impairment progresses with the progression of the disease [18]. Therefore, given the lack of age effect reported in dual tasking, once individual component tasks are titrated, coupled with clear impairment in AD, dual-tasking is an ideal instrument to assess (together with retentive memory measures) and follow-up cognition in people with AD as well as detecting any change due to treatment.

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